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WATER BALANCE ANALYSIS USING PALMER DROUGHT SEVEREITY INDEX FOR DROUGHT-PRONE REGION OF MARATHWADA, INDIA

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Keywords: water balance, soil moisture deficit, water surplus, drought, PDSI

Highlight:

- Water balancing approach can effectively help in modelling the rapid depletion of water resources.
- This work expands the use of drought indicators for water balancing by evaluating the soil moisture deficit or surplus with spatial and temporal changes for the Marathwada region for 1957-2017.
- Urban system sectors may augment short-term and long-term policies based on the framework to overcome the water crisis for a balanced water resource.

Abstract:

Sustainable water resource management is the immediate priority as the rapid depletion of water resources is aggravating drought conditions in many regions worldwide. One of the possible approaches to recover from such a condition is through water resource balancing. The water balance studies require knowledge of water availability for various sectors' present and future requirements to balance the water resource. The present study uses the Palmer Drought Severity Index (PDSI) for water balancing. It evaluates the soil moisture deficit or surplus with spatial and temporal changes for the Marathwada region consisting of eight districts for 1957-2017. The analysis shows water surplus from July to September and water deficit from November to May. The study observes that the Marathwada is drought-free during the Kharif season and water deficit in Rabi season. This study analyses the need for crop-shift to avoid crop damage during drought. Based on the analysis, all the urban system sectors need to augment short-term and long-term policies to overcome the water crisis for a balanced water resource. The Self-Calibrated PDSI (ScPDSI) is calculated based on PDSI, which gives more freedom in analyzing the drought period.

Declaration:

The submitted work is original and is not published anywhere in any form or language. The manuscript is not submitted to more than one journal. The study is not split into several parts to increase the quantity of the publication. Required acknowledgment is given wherever required.

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1. INTRODUCTION

Drought is a long-term phenomenon lasting from months to years, causing significant ecological and economic damage (UNISDR, 2015; WMO, 2000). It manifests the concern of depletion in surface and groundwater resources and crop failure (NAAS, 2011). There is an expected increase in drought severity and frequency with climate change (Vasiliades et al., 2011; Wilhite et al., 2014). The future projection of available water signifies the annually increasing gap between water demand and supply (C. Sharma & Sharma, 2017). Sustainable water resources management is one of the key aspects of effective water management (Van & Marques, 2012).

Water balance studies are becoming vital due to the increasing demand for freshwater in the domestic, industrial, and agricultural sectors (Aquastat, 2011; Arjun, 2017). Water balance is considered one of the important components while planning irrigational schemes in drought-prone areas (Arjun, 2017). It requires knowledge of water availability for current and impending conditions for various sectors to balance the water resource (Sokolov & Chapman, 1974). It is calculated based on three components, which are potential evapotranspiration (PET), monthly rainfall, water surplus or deficit (moisture departure) (Arjun, 2017; Mintz & Serafini, 1992). The net change in the supply and demand of water define7s moisture departure (Mckee et al., 1993; Vasiliades & Dalezios, 2002). Supply is precipitation and stored soil moisture (Mckee et al., 1993), whereas demand is potential evapotranspiration (PET) and runoff. PET is the amount needed to recharge the soil, and runoff keeps the rivers, lakes, and reservoirs at a normal level.

Numerous studies are associated with water balance indicating the soil moisture deficit, runoff, and drought severity (Edossa et al., 2010; Vasiliades et al., 2011; Vasiliades & Dalezios, 2002; Vicente Serrano & Lopez Moreno, 2005). Some drought studies have been published on the development and application of indices derived from meteorological and hydrological datasets such as PDSI, SPI, SWI, SPEI, etc. (Quiring, 2009; White & Walcott, 2009). Few studies have developed a method using satellite data like Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EHI), Vegetation Health Index (VHI), etc. (Belal et al., 2014; Bhuiyan, 2008; T. C. Sharma, 2000). However, the need is to develop a systematic water balance approach through drought indices, indicating significant temporal and spatial changes over the year. Keyantash & Dracup (2004) assessed the water balance for a region using a hydrological drought index, i.e., PDSI. The PDSI (Palmer, 1965a) is a meteorological drought indicator used extensively (Guhathakurta et al., 2017) in water balancing. The study region undergoes long-term drought, and PDSI is known for successfully quantifying such drought situations. Hence, the present study conducts the evaluation of a drought-prone region for balanced water resources based on PDSI.

2. STUDY REGION

The analytical study of water balance is conducted for Marathwada, a semiarid region of Maharashtra (Figure 1). It consists of eight districts: Aurangabad, Jalna, Hingoli, Beed, Latur, Nanded, Parbhani, and Osmanabad. The area occupied by the region is 64,590 square kilometers, and the population size is 18,731,872 as per the 2011 census. The region is known for its severe and frequent drought. It has suffered an increasing trend of rainfall deficit over the years, which majorly affects the agricultural needs. The chemical composition of the soil is rich in calcium and magnesium carbonate but is deficient in nitrogen and phosphorous, leading to frequent cracking up of soil during summer (LMC, 2006). The region develops its significant share of the economy from the agricultural sector (LMC, 2006). The major crops grown in the Marathwada region during the Kharif season (June-October) are Groundnut, Cotton, Sugarcane, and during the Rabi season (Winter season: November-April) are Maize, Wheat, sunflower. These crops are water-intensive crops that deteriorate the groundwater levels. In 2015, the precipitation levels decreased by about 50% of normal average rainfall, significantly affecting the districts (IMD, n.d.; Katalakute et al., 2016). Table 1 gives a brief idea about the deficit in rainfall for subdivisions of Maharashtra in the year 2015. The districts of Marathwada, like Beed (287.4mm, -50%), Latur (372mm, -51%), Parbhani (344.9mm, -54%), have received 50% or less than the average rainfall in 2015. Drought in 2016 resulted in a significant number of farmer suicide due to severe losses in crop and livestock production. Water supplies to the public and industrial sectors were affected due to reduced surface and groundwater supplies during a drought in 2015-16. Figure 2 shows the agroclimatic zones of Maharashtra. The scarcity plains zone is located at an average altitude of 600 mean sea level, encompasses western parts of Beed, Osmanabad, and Aurangabad.

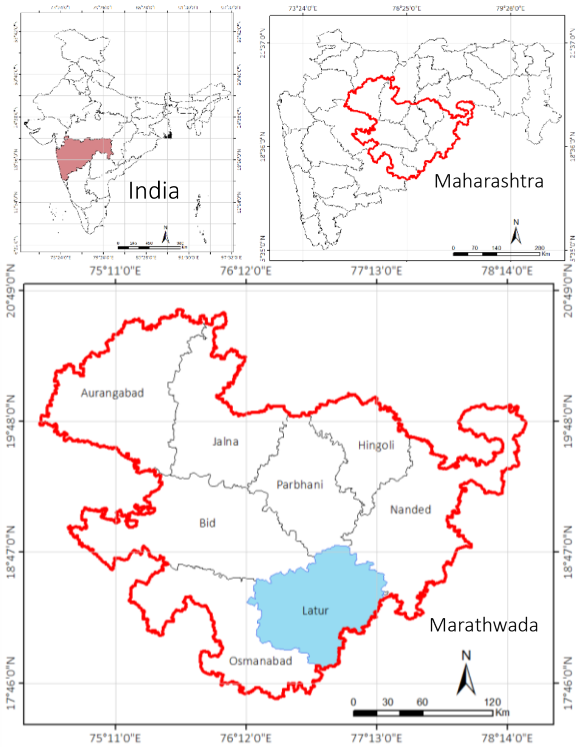


Figure 1: Map showing Geographical location of Marathwada region

Table 1: Region wise Rainfall data in Maharashtra for 2015 as per IMD, Pune

Rainfall (in mm)		Konkan	Vidarbha	Madhya Maharashtra	**Marathwada**
June	Normal	663	161	140	138
	Actual	781	254	177	119
July	Normal	1147	318.9	247.8	192.5
	Actual	581.5	137.8	117.7	26.8
August	Normal	759.6	305.7	289.1	188.2
	Actual	388.7	288.9	56	112.2
September	Normal	344.7	169	152.4	164.2
	Actual	253.8	167.5	143.4	154
Monsoon	Normal	2914.3	954.6	729.3	682.9
	Actual	**2005.0**	**848.2**	**488.1**	**412.4**

3. METHODOLOGY

Using a drought indicator, the study assesses the necessity of water balancing in drought-prone locations. There are various drought indicators available for water balance studies as mentioned in handbook of drought indicators by Svoboda & Fuchs, (2016) such as Aridity Anomaly Index (AAI), Drought Reconnaissance Index (DRI), Soil Moisture Anomaly (SMA) etc. As a result,

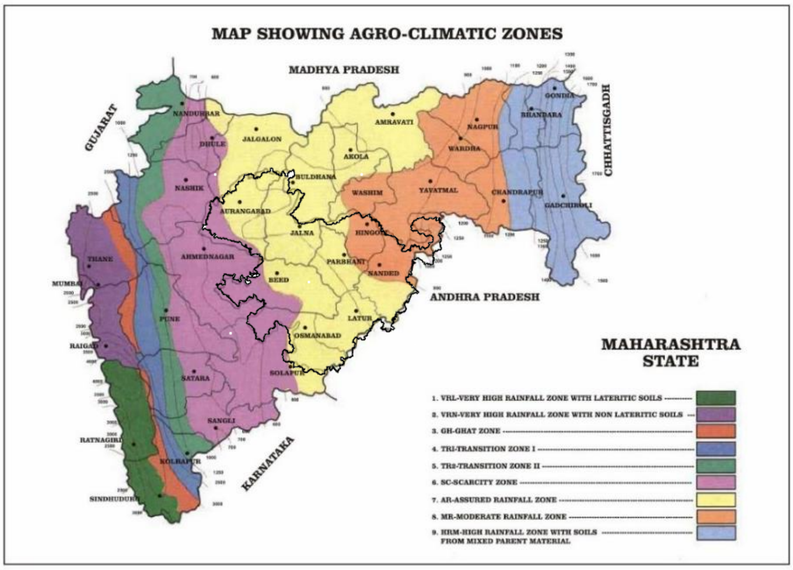


Figure 2: Agroclimatic zones of Maharashtra
Source: Water Resource Department, Department of Agriculture, Government of Maharashtra, Report of Water Audit, 2005

a widely used meteorological drought indicator, the PDSI, is used to analyse the water balance as it identifies droughts in crop-producing regions. The water balance approach is used to examine the imbalance caused by agriculture in the Marathwada region. The approach and process used to compute the region's water balance are depicted schematically in Figure 3. PDSI determines the drought coefficient by analysing the region's wet and dry months. The study uses Available water Content (AWC)[1] of the soil, monthly PET, and monthly

[1] AWC data is derived for each station from Soil and Land Use Survey of India (SLUSI), Department of Agriculture, Ground Survey and Development Agency, Maharashtra

precipitation levels for the past 60 years from eight data stations. The monthly average moisture departure is determined for the period 1957-1990 (base years) and 1991-2017 (observation years), and temporal variations are noted over these years. The water balance analysis is divided into two distinct periods based on the World Meteorological Organization's climate normals (WMO). Climate normals serve as a baseline against which current climatological patterns are compared to those of the past or to what is deemed normal. A normal is defined as the arithmetic average of a climate variable over a period of 30 years (e.g., precipitation, temperature). Generally, a period of 30 years is utilised because it is long enough to eliminate interannual volatility or anomalies while being short enough to demonstrate longer climatic trends. As a result, we compared the base year period of 1957 to 1990 to the current climatic conditions for 1991 to 2017.

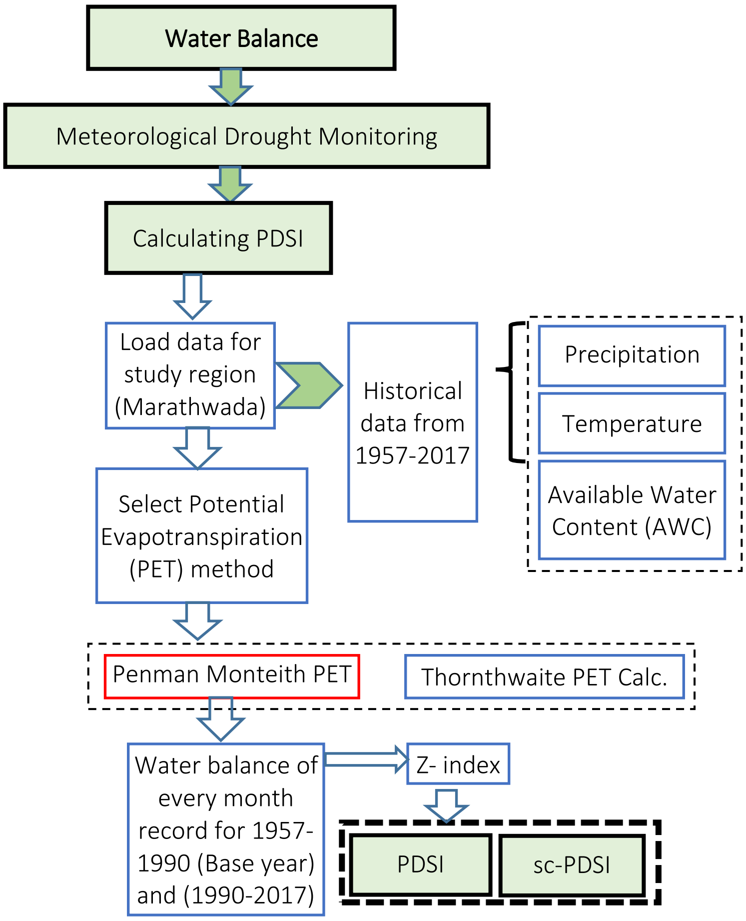


Figure 3: A schematic diagram showing the methodology.

3.1 Palmer Drought Severity Index (PDSI)

Various drought indicators given by World Meteorological Organisation are listed in the Handbook of drought indices and indicators for analyzing drought severity. The PDSI is a two-stage bucket model of the soil developed by Palmer (1965). PDSI is categorized as a meteorological drought index, and it quantifies the water departure from soil surface (Svoboda et al., 2017). It is widely used to study temporal aridity changes in climates (Sivakumar et al., 2011). The standardized measure of PDSI ranges from −4 (dry) to +4 (wet), with values below −3 representing severe to extreme drought (Palmer, 1965b) (Table 2). It incorporates past and present moisture supply (precipitation) and demand (PET) into a hydrological system (Palmer, 1965; Wells et al., 2004). AWC was taken as 100mm for the study (25.4 mm (1 inch) as the first top-soil layer according to Palmer 1965 and 76.4 as the second soil layer). Marathwada is 65% covered with black soil and approximately 22% with coarse and shallow soil. All the regions would not hold 100mm of AWC, but it was a rational figure given by the Ground Survey and Development Agency (GSDA) of Marathwada as a whole. The study will not get affected due to a slight difference in AWC as the precipitation is ordinarily insufficient to provide more than 26 mm of stored moisture. The other challenge is to compute runoff, which varies from place to place and depends on the topography, soil moisture condition. Feasibly, runoff can also be calculated as a function of deficiency and precipitation (Kohler, M.A., Linsley, 1951). It is assumed that there will be no recharge to the underlying portion of the root zone until the topmost surface layer has been brought to its field capacity (Palmer, 1965a). It is also assumed that the loss from the underlying layer will depend on PET, AWC, and initial moisture content, which is given by:

Table 2: PDSI categorization of drought severit

PDSI value	**Drought category**
4.00 or more	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to −0.49	Near normal
−0.50 to −0.99	Incipient dry spell
−1.00 to −1.99	Mild drought
−2.00 to −2.99	Moderate drought
−3.00 to −3.99	Severe drought
−4.00 or less	Extreme drought

$$\mathrm{Ls} = \left(\mathrm{S_s}\ \text{or}\left(\mathrm{PE} - \mathrm{P}\right)\right),\ \text{whichever is smaller} \tag{1}$$

$$\mathrm{Lu} = \frac{\left(\mathrm{PE} - \mathrm{P} - \mathrm{L_s}\right)\mathrm{Su}}{\mathrm{AWC}},\ \ \mathrm{Lu} \le \mathrm{Su} \tag{2}$$

Where, Ls = moisture loss from top surface layer; Ss =available moisture stored in surface layer; PE = Potential Evapotranspiration for the month; Lu=Loss from underlying levels; Su-available moisture stored in underlying levels at start of the month AWC=Combined AWC of both levels

Palmer (1965b) describes the detailed method to calculate PDSI using a one-month time step. Each of the months has four values related to its soil moisture along with its complementary potential values. These values are Evapotranspiration (ET), Runoff (RO), recharge(R), loss (L), potential evapotranspiration (PE), potential recharge (PR), potential runoff (PRO), and potential loss (PL) (Palmer, 1965a; Wells et al., 2004). The potential recharge is the amount of moisture required to bring soil to its water holding capacity. The potential loss is the amount of moisture lost from the soil due to evapotranspiration when precipitation levels are zero. The potential runoff is the difference between precipitation and PR (Szép et al., 2005). PET calculated using the Thornthwaite equation gives an overestimated drought condition. Hence, PET is calculated using the Penman-Monteith equation (Schrier et al., 2011) for the present study. The four potential values are weighted according to the climate of the area using α, β, γ, and δ to give the climatically appropriate for existing conditions (CAFEC) potential values. These potential values are called water balance coefficients.

$$\alpha = ET/PE \quad (3) \qquad \beta = R/PR \quad (4)$$

$$\gamma = RO/PRO \quad (5) \qquad \delta = L/PL \quad (6)$$

CAFEC potential values are combined to form CAFEC precipitation, Ṕ represents the amount of precipitation required to maintain the soil moisture for a respective month (Wells et al., 2004). Next, moisture departure (d) is calculated from the difference of actual precipitation of a specific month and the computed potential values. The product of soil moisture departure and climate characteristics gives a moisture anomaly index (Z-index).

$$\acute{P} = \alpha PE + \beta PR + \gamma PRO - \delta PL \quad (7)$$

$$d = P - \acute{P} \quad (8)$$

The Z index[2] is the product of moisture departure and K (a climatic characteristic which is a refinement of K’ as per the location). The purpose of K is to adjust the values of moisture departure according to climatic characteristics.

[2] All the equations are directly taken from Palmer's (1965a) paper

$$K' = 1.5\, log_{10}\left[\frac{\frac{PE+R+Ro}{P+L}+2.8}{D}\right] + 0.5 \quad (9)$$

$$K = \frac{17{\cdot}67}{\Sigma DK'} K' \quad (10)$$

$$Z = dK \quad (11)$$

Further, self-calibrated PDSI (scPDSI) is calibrated for the same period 1957-2017, based on the proposed theory of Wells et al. (2004) using R. According to Wells's theory, ScPDSI can automatically adjust the empirical constants used in PDSI computation with dynamically calculated values. PDSI values sometimes cannot gather satisfactory results to make the spatial comparison within a region.

4. RESULTS AND DISCUSSION

The global water balance has changed intensely due to natural and anthropogenic influences. The present study states the water balance elements stating the condition of the Marathwada region in table 3. Table 3 shows maximum recharge in July as the precipitation levels are highest and the PET values are less. The PET in August and September is low, and precipitation levels are higher; hence the recharge is low. In June, the precipitation level is 136.73 mm, but the PET is also high, i.e. 117.11 mm thus, the recharge drops down to 30.3 mm. The calculation of coefficients is presented in table 4, where CAFEC potential values for shown. Table 5 shows the monthly average departure for the period 1957- 2017.

Table 3: The average values of the water balance elements for the analysed period (All the parameters are measured in mm)

	Actual ET	Potential ET	Recharge	Soil storage (previous month)	Potential recharge	Runoff	Deficit	Loss	Storage surface	Potential loss	Potential runoff	Precipitation	Moisture Departure
	ET	**PE**	**R**	**S'**	**PR**	**RO**	**M**	**L**	**Ss**	**PL**	**PRO**	**P**	**d**
Jan	10.88	91.77	0.00	8.22	91.73	0.00	80.88	7.04	0.00	7.32	8.27	3.84	9.44
Feb	4.34	104.98	0.00	1.23	98.77	0.00	100.64	1.19	0.00	1.29	1.23	3.15	**4.77**
Mar	7.10	128.23	0.03	0.04	99.96	0.00	121.13	0.08	0.00	0.06	0.04	7.02	7.34
Apr	6.42	142.99	0.02	-0.01	**100.01**	0.00	**136.57**	0.01	0.00	-0.01	-0.01	6.41	5.43
May	15.39	**149.12**	0.00	0.00	100.00	0.00	133.72	0.00	0.00	0.00	0.00	15.39	12.81
Jun	**103.73**	117.11	31.30	0.00	100.00	1.70	13.38	0.00	12.65	0.00	0.00	136.73	47.49
Jul	51.02	51.78	**60.04**	31.30	68.70	73.48	0.76	0.09	24.34	17.48	31.30	**184.45**	73.94
Aug	45.43	45.43	7.46	91.25	8.75	**126.64**	0.00	0.00	**25.40**	37.81	91.25	179.53	73.42
Sep	51.94	51.94	0.57	98.71	1.29	118.32	0.00	0.34	25.06	44.82	98.71	170.50	68.53
Oct	57.87	60.01	0.11	**98.95**	1.05	23.98	2.14	16.95	13.61	50.88	**98.95**	65.01	43.22
Nov	71.65	91.11	0.63	82.10	17.90	1.38	19.46	**53.27**	1.45	**65.85**	82.10	20.39	23.28
Dec	29.21	87.46	0.37	29.46	70.54	0.00	58.25	22.89	0.35	24.84	29.46	6.69	17.21

	ET/PE	R/PR	RO/PRO	L/PL	(PE+R)/(P+L)	(PE+R+RO)/(P+L)		Z- Index	Climatic Characteristics
	α	**β**	**γ**	**δ**	**k**	**T**	**Ḱ**	**DḰ**	**K**
Jan	0.119	0.000	0.000	0.962	8.431	1.000	0.669	6.315	0.055
Feb	0.041	0.000	0.000	0.924	24.207	1.000	0.801	3.818	0.066
Mar	0.055	0.000	0.000	1.406	18.061	1.004	0.712	5.228	0.059
Apr	0.045	0.000	0.000	-0.762	22.271	1.002	0.772	4.190	0.064
May	0.103	0.000	0.000	0.000	9.688	1.000	0.629	8.058	0.052
Jun	0.886	0.313	0.000	-0.166	1.085	1.000	0.537	25.590	0.044
Jul	0.985	0.874	2.348	0.005	0.606	1.000	0.524	38.762	0.043
Aug	1.000	0.853	1.388	0.000	0.295	1.000	0.524	38.502	0.043
Sep	1.000	0.445	1.199	0.008	0.307	1.000	0.526	36.055	0.043
Oct	0.964	0.101	0.242	0.333	0.734	1.000	0.541	23.375	0.045
Nov	0.786	0.035	0.017	0.809	1.245	1.000	0.574	13.360	0.047
Dec	0.334	0.005	0.000	0.921	2.970	1.000	0.598	10.293	0.049
							SUM DḰ	209.98788	

Table 4: Calculation of Coefficients

Table 5: Table shows monthly soil moisture departure for 1957-2017 in mm

MOISTURE DEPARTURE - d												
Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1957	10.10	0.02	6.82	8.16	14.73	-9.15	105.01	110.18	-65.80	-10.50	-10.88	-10.62
1958	-8.29	-4.09	-2.70	18.81	-2.50	-46.64	127.21	271.47	-89.43	-20.56	32.26	12.45
1959	-3.23	-3.60	-7.17	3.09	-2.22	38.11	-29.96	15.58	77.29	38.34	4.09	3.05
1960	-2.67	-3.82	11.03	-5.44	33.85	28.85	-70.26	-118.90	35.88	14.75	1.12	0.42
1961	-5.84	-3.69	-1.36	0.23	20.48	36.61	38.45	-41.02	-73.29	176.64	-7.48	-2.54
1962	-6.30	-1.09	-4.38	31.48	28.18	-68.38	26.25	6.71	134.41	-22.96	16.47	55.36
1963	11.84	4.03	8.39	0.67	-1.85	92.91	-114.87	196.40	-88.54	28.81	-10.15	-6.44
1964	-7.81	-3.89	-2.11	-4.95	-14.10	-16.86	105.65	-35.00	51.31	-43.80	-10.82	-16.59
1965	-3.67	-2.58	-7.13	3.16	-14.14	-9.17	68.47	-6.76	-102.16	-59.98	-35.78	-16.20
1966	8.82	-4.14	3.19	4.05	30.53	-72.02	88.05	-101.93	19.41	-53.03	34.82	19.66
1967	-0.94	-3.53	-3.12	-5.47	-9.45	9.02	46.76	-81.17	-34.50	-39.02	-23.83	87.90
1968	23.99	22.33	26.19	4.91	-14.57	-41.85	79.92	-122.10	37.77	-41.23	1.43	-10.12
1969	-8.27	-4.09	-7.01	-6.41	-12.61	-16.18	80.91	-38.68	108.09	-49.81	8.57	-6.59
1970	0.81	-3.67	-4.33	1.10	14.83	82.59	-182.13	160.27	8.45	-44.15	-26.42	-25.31
1971	-9.87	-4.18	-5.77	-6.29	23.49	-47.27	-113.73	86.34	-40.06	46.18	-13.45	-10.01
1972	-8.16	-4.02	-7.20	-6.29	-12.14	-23.37	-101.79	-47.72	-61.67	-60.90	-34.64	-21.07
1973	-10.14	-3.58	-7.12	-2.61	-14.97	-23.93	65.70	151.33	-52.99	38.15	-11.88	-7.43
1974	-7.57	-3.67	-6.84	-3.53	20.32	-35.60	-40.06	-34.10	-19.27	73.56	-13.48	-10.19
1975	-6.11	4.35	0.34	-6.45	-3.92	-17.36	110.27	45.57	143.85	53.36	-12.98	-8.68
1976	-7.61	-3.75	-3.98	1.07	-12.47	-44.13	75.18	10.75	-107.71	-62.84	2.96	-6.74
1977	-7.63	-2.55	-1.19	-1.74	-9.67	-8.93	3.94	-35.76	-53.70	2.04	117.31	42.77
1978	24.62	19.92	4.29	5.80	3.73	79.72	-65.65	-77.63	-89.69	6.75	21.75	13.86
1979	-0.34	8.56	-1.33	-5.07	2.86	-12.78	14.37	-53.44	66.00	-46.35	64.10	23.17
1980	-1.08	-3.36	-2.54	-1.77	-13.25	89.55	-169.75	141.53	-56.90	-66.30	-36.29	-5.16
1981	18.14	-3.02	3.89	-4.78	-2.61	-34.43	-15.31	-42.84	114.81	4.65	-1.65	17.04
1982	9.03	-1.75	-2.19	1.37	0.76	-35.33	30.81	-101.11	-1.25	-20.76	10.52	-1.65
1983	-7.26	-3.98	-6.84	-6.09	-9.35	-40.36	90.93	128.64	251.80	43.66	-11.73	-0.08
1984	-2.72	5.81	-6.68	-5.54	-15.48	-60.35	30.27	-125.26	-50.61	41.39	-7.48	-1.60

1985	0.30	-3.71	-1.07	4.07	-7.84	25.87	-53.32	-120.95	-90.53	22.25	-12.15	-6.18
1986	1.97	5.93	-5.81	-3.72	-8.18	-3.19	-20.42	-57.53	-66.92	-58.52	-24.68	-9.61
1987	-1.01	-0.41	-6.29	-4.46	5.68	18.87	-61.55	34.71	-127.15	81.17	28.05	26.94
1988	0.81	-3.28	-7.10	0.81	-11.20	33.46	88.64	59.91	240.56	-45.55	-19.17	-17.04
1989	-9.25	-4.20	35.28	-3.53	-9.08	103.15	51.01	60.43	-0.50	-46.30	-26.93	-15.80
1990	-6.86	-4.21	-7.01	-6.46	126.96	89.23	-153.15	181.05	-67.57	160.27	-7.88	-2.24
1991	-6.50	-3.56	-6.82	3.41	-6.02	114.42	-62.37	-135.15	-133.27	-55.23	-30.11	-22.54
1992	-9.86	-4.19	-7.13	-2.91	-8.65	81.67	-207.88	17.09	-30.10	-12.16	8.77	0.87
1993	-6.49	-2.94	-1.47	-4.66	-6.25	-50.04	76.59	-19.93	-48.70	72.25	-7.36	49.59
1994	10.35	-1.82	-7.39	8.51	-1.05	-25.08	-20.51	-3.92	-107.31	-0.06	19.94	11.38
1995	41.99	-0.49	16.12	5.04	2.25	-0.18	22.45	-88.85	-32.81	88.84	-11.76	-7.65
1996	-7.41	-3.94	-6.82	4.19	-13.45	-80.62	47.10	59.21	57.18	54.54	-8.62	-5.57
1997	-0.13	-2.79	1.10	7.86	-7.50	-62.29	-8.92	-49.04	-9.00	44.27	85.58	90.29
1998	50.83	2.53	-4.20	-4.44	-6.67	52.25	12.61	61.43	63.18	83.81	19.07	11.81
1999	-4.28	2.16	-6.97	-6.47	2.55	3.59	-38.50	-54.00	46.81	56.31	-12.91	-8.22
2000	-7.46	-0.19	-6.58	-6.13	1.36	55.60	-89.34	54.23	-122.52	-34.76	-22.63	-22.84
2001	-5.48	-3.63	-6.58	3.37	-14.61	18.79	-136.47	102.39	-91.02	103.10	-12.42	-8.79
2002	-2.40	0.20	-6.38	-0.29	-6.92	109.47	-225.11	40.46	-51.06	-17.80	-11.03	-13.28
2003	-6.56	-2.82	-4.97	-1.73	12.37	-16.77	111.24	7.36	-78.40	-48.96	-27.31	-25.19
2004	-9.28	-3.93	-1.75	-4.80	14.35	-40.88	61.99	-107.72	8.61	-10.07	12.32	2.57
2005	6.39	-2.69	4.21	-5.06	-13.66	-80.63	274.84	-59.47	40.25	30.50	-13.85	-11.74
2006	-9.14	-4.25	23.37	-5.03	10.94	4.60	-57.52	131.04	34.24	-21.84	-13.35	-19.96
2007	-10.05	-4.40	-7.35	-5.94	-5.79	50.84	-112.20	-35.24	67.45	-65.89	-32.21	-24.66
2008	-10.38	-4.26	7.25	-2.99	-14.18	-65.44	-32.58	1.84	93.70	-38.48	-26.12	-28.66
2009	-10.90	-4.48	-6.79	-5.85	-8.92	-69.41	8.73	-5.88	-17.37	-10.84	47.61	31.22
2010	3.06	2.34	-3.38	-6.12	-11.19	-13.00	186.75	111.03	-16.80	-15.35	19.62	1.78
2011	-7.66	-0.15	-6.37	-2.98	-12.53	-54.62	86.20	52.17	-81.13	-43.52	-27.48	-25.98
2012	-10.13	-4.29	-7.13	-5.77	-13.27	-61.80	25.80	-77.27	-53.46	2.62	-12.98	-9.30
2013	-6.68	5.47	-4.39	1.34	-9.06	27.27	88.45	-44.33	-17.67	24.46	-6.25	6.84
2014	-3.11	9.66	71.91	5.35	-8.40	-98.96	-35.13	23.64	-91.29	-53.36	-12.87	-13.97
2015	1.23	-2.44	24.75	33.18	-3.10	-11.80	-115.94	-15.71	3.08	-45.77	-22.89	-23.36
2016	-10.42	-1.17	3.59	-3.59	-8.99	29.81	68.55	-94.16	127.14	32.94	-13.45	-9.93
2017	-8.72	-4.33	-2.57	-6.51	-12.25	46.62	-148.89	50.96	-25.93	37.72	-10.88	-5.22

The PET values in the graph from January to May are more than the monthly average precipitation, as shown in Figure 4. It shows the water store is being used up by vegetation or lost by evaporation, making it drought-prone and water deficit period. The precipitation levels during June, July, August, and September are more than PET.

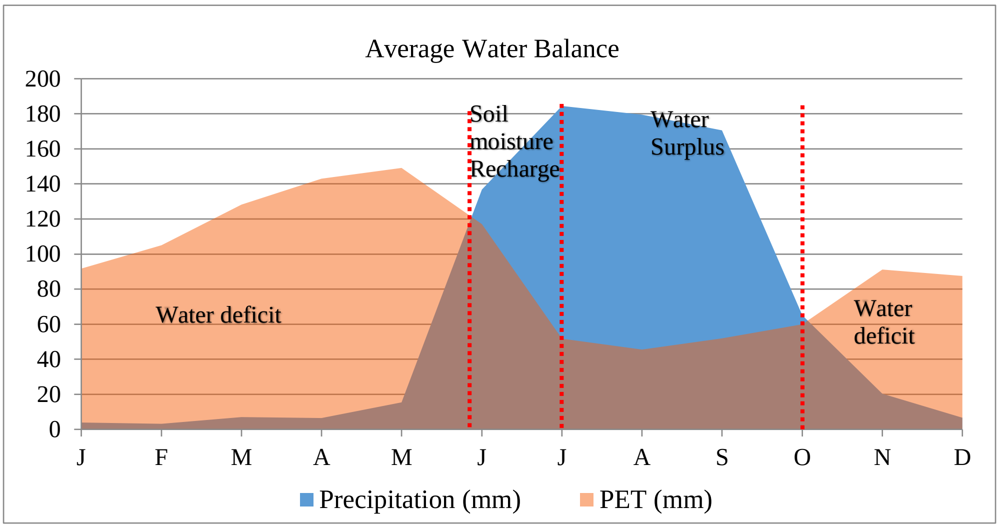


Figure 4: Average water balance of Marathwada calculated for the period of 1957-2017

It denotes the soil water store is full, leading to surplus water and better crop production. These are the Kharif crop season; therefore, a crop grown during this season will have a sufficient quantity of soil moisture. But, the major Kharif crops grown in the region are sugarcane, soybean, and cotton. They are water-intensive crops, thereby reduces the soil moisture leading to poor groundwater conditions or soil moisture deficits. The region undergoes a radical imbalance of water resources.

Table 6: Table shows Average soil moisture deficit for the two periods in mm

	1957-1990	1991-2017
Jan	81.03	83.26
Feb	100.69	102.64
Mar	122.24	119.51
Apr	135.79	138.28
May	132.97	136.11
Jun	11.39	16.44
Jul	1.41	0.42
Aug	0.00	0.00
Sep	0.00	0.00
Oct	2.78	1.69
Nov	19.19	20.72
Dec	54.13	62.53
Total	**661.62**	**681.60**

The monthly average soil moisture deficit is shown in table 6. It shows the change in soil moisture deficit between the reference period (1957-1990) and the period after 1990 is 3.02%. The observed number of extreme to severe drought months after 1990 was more than the number of drought years before 1990 (Figure 5). Due to reduced precipitation levels and

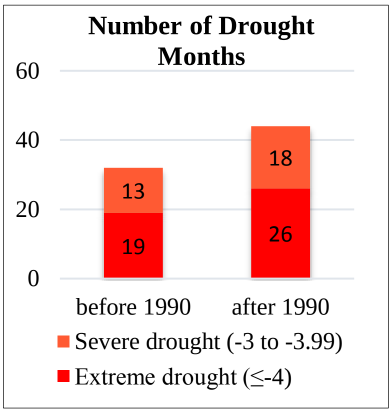


Figure 5:Number of severe and extreme drought month.

prolonged dry spell in 2015, especially from September to December, 40% to 50% yield of the soybean crop in soil with low water holding capacity of the region was lost, as reported by the agricultural department. Sugarcane plantations in the Latur district suffered 65% to 70% yield decline. There was a clear decline in rabi (winter) crop sown due to deficient rainfall and low soil water moisture. The monsoon months (June-September) show a considerably dry period for the maximum years leading to drought conditions. The spatial interpretation of the same is done using kriging method as shown in figure 7. The drought severity is high from September to December. Later, drought severity frequency distribution is calculated for the Z- index for the period 1957-1990, as shown in table 7. It shows a considerable number of months under moderate to severe drought frequency while some under extreme drought conditions. Table 8 shows the monthly Z- index. The future drought events can be estimated from the previous year's PDSI values. Hence, early warning of drought events can be prepared.

Table 7: Table shows drought severity frequency distribution.

(Z-Index)	**Before 1990**		**After 1990**		**Whole analyzed period**	
	Number of cases	Relative frequency	Number of cases	Relative frequency	Number of cases	Relative frequency
Extremely wet (≥4)	32	6.72	28	7.63	60	7.12
Very wet (3 to 3.99)	13	2.73	13	3.54	26	3.08
Moderately wet (2 to 2.99)	24	5.04	16	4.36	40	4.74
Slightly wet (1 to 1.99)	42	8.82	19	5.18	61	7.24
incipient wet spell (0.5 to 0.99)	21	4.41	11	3.00	32	3.80
Near normal (0.49 to -0.49)	196	41.18	142	38.69	338	40.09
Incipient drought (-0.5 to -0.99)	54	11.34	52	14.17	106	12.57
Mild drought (-1 to -1.99)	29	6.09	29	7.90	58	6.88
Moderate drought (-2 to -2.99)	33	6.93	13	3.54	46	5.46

Severe drought (-3 to -3.99)	13	2.73	18	4.90	31	3.68
Extreme drought (≤-4)	19	3.99	26	7.08	45	5.34
Total number of months	**476**		**367**		**843**	

Also, the non-parametric Mann-Kendall's trend test is applied over 1957- 2017 using R. Mann Kendall's test is useful as it is not directly based on the random values but on the significance of differences, which is important to identify the monotonic trends in the hydro-meteorological data (such as precipitation, temperature) (Daneshvar Vousoughi et al., 2013). The test shows a p-value of 0.064, which is above the level of significance 0.05 (95% confidence interval), negative Sen's slope of -0.00375, Kendall's tau of -0.0464 showing the significant decreasing trend of precipitation level and increasing trend of drought (negative the SPI values, more is the drought severity). The necessary actions should be taken for effective policy formation considering the drought severity of the region. The trend result can be validated through the early warning declaration by the Government of Maharashtra for 32 districts to be drought-prone. The PDSI is calculated for 1957-2017 to quantify the region's long-term drought severity and is plotted in figure 6.

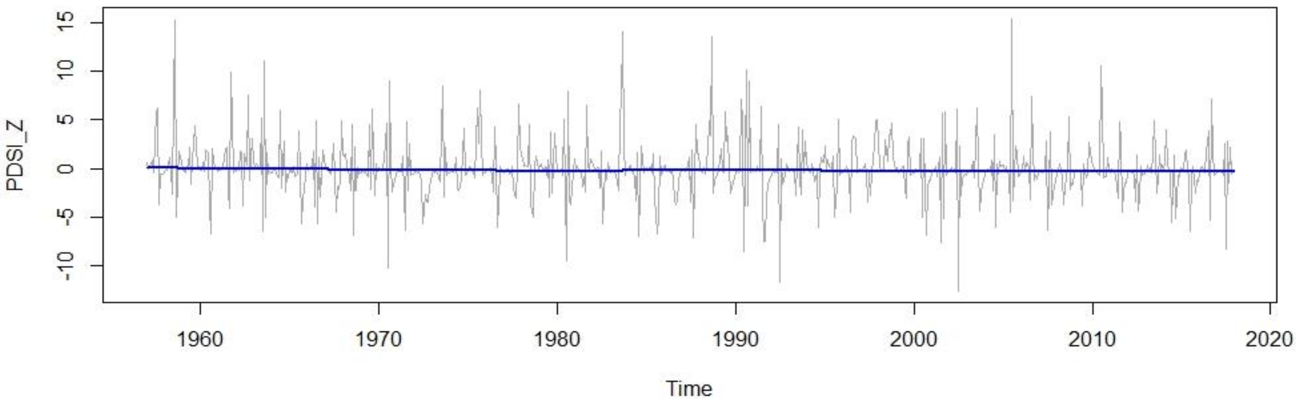


Figure 6: PDSI based Z index for the period of 1957-2017

Table 8: Table shows monthly Z index for 1957-2017

Z-INDEX - Moisture anomaly index												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1957	0.6	0.0	0.4	0.5	0.8	-0.5	5.9	**6.2**	**-3.7**	-0.6	-0.6	-0.6
1958	-0.5	-0.2	-0.2	1.1	-0.1	-2.6	7.2	15.3	-5.0	-1.2	1.8	0.7
1959	-0.2	-0.2	-0.4	0.2	-0.1	2.1	-1.7	0.9	4.3	2.2	0.2	0.2
1960	-0.2	-0.2	0.6	-0.3	1.9	1.6	-4.0	-6.7	2.0	0.8	0.1	0.0
1961	-0.3	-0.2	-0.1	0.0	1.2	2.1	2.2	-2.3	-4.1	9.9	-0.4	-0.1
1962	-0.4	-0.1	-0.2	1.8	1.6	-3.8	1.5	0.4	7.6	-1.3	0.9	3.1
1963	0.7	0.2	0.5	0.0	-0.1	5.2	-6.5	11.0	-5.0	1.6	-0.6	-0.4
1964	-0.4	-0.2	-0.1	-0.3	-0.8	-0.9	5.9	-2.0	2.9	-2.5	-0.6	-0.9
1965	-0.2	-0.1	-0.4	0.2	-0.8	-0.5	3.9	-0.4	-5.7	-3.4	-2.0	-0.9
1966	0.5	-0.2	0.2	0.2	1.7	-4.1	5.0	-5.7	1.1	-3.0	2.0	1.1
1967	-0.1	-0.2	-0.2	-0.3	-0.5	0.5	2.6	-4.6	-1.9	-2.2	-1.3	4.9
1968	1.3	1.3	1.5	0.3	-0.8	-2.4	4.5	-6.9	2.1	-2.3	0.1	-0.6
1969	-0.5	-0.2	-0.4	-0.4	-0.7	-0.9	4.6	-2.2	6.1	-2.8	0.5	-0.4

1970	0.0	-0.2	-0.2	0.1	0.8	4.6	-10.2	9.0	0.5	-2.5	-1.5	-1.4
1971	-0.6	-0.2	-0.3	-0.4	1.3	-2.7	-6.4	4.9	-2.3	2.6	-0.8	-0.6
1972	-0.5	-0.2	-0.4	-0.4	-0.7	-1.3	-5.7	-2.7	-3.5	-3.4	-1.9	-1.2
1973	-0.6	-0.2	-0.4	-0.1	-0.8	-1.3	3.7	8.5	-3.0	2.1	-0.7	-0.4
1974	-0.4	-0.2	-0.4	-0.2	1.1	-2.0	-2.3	-1.9	-1.1	4.1	-0.8	-0.6
1975	-0.3	0.2	0.0	-0.4	-0.2	-1.0	6.2	2.6	8.1	3.0	-0.7	-0.5
1976	-0.4	-0.2	-0.2	0.1	-0.7	-2.5	4.2	0.6	-6.1	-3.5	0.2	-0.4
1977	-0.4	-0.1	-0.1	-0.1	-0.5	-0.5	0.2	-2.0	-3.0	0.1	6.6	2.4
1978	1.4	1.1	0.2	0.3	0.2	4.5	-3.7	-4.4	-5.0	0.4	1.2	0.8
1979	0.0	0.5	-0.1	-0.3	0.2	-0.7	0.8	-3.0	3.7	-2.6	3.6	1.3
1980	-0.1	-0.2	-0.1	-0.1	-0.7	5.0	-9.5	8.0	-3.2	-3.7	-2.0	-0.3
1981	1.0	-0.2	0.2	-0.3	-0.1	-1.9	-0.9	-2.4	6.5	0.3	-0.1	1.0
1982	0.5	-0.1	-0.1	0.1	0.0	-2.0	1.7	-5.7	-0.1	-1.2	0.6	-0.1
1983	-0.4	-0.2	-0.4	-0.3	-0.5	-2.3	5.1	7.2	14.2	2.5	-0.7	0.0
1984	-0.2	0.3	-0.4	-0.3	-0.9	-3.4	1.7	-7.0	-2.8	2.3	-0.4	-0.1
1985	0.0	-0.2	-0.1	0.2	-0.4	1.5	-3.0	-6.8	-5.1	1.3	-0.7	-0.3
1986	0.1	0.3	-0.3	-0.2	-0.5	-0.2	-1.1	-3.2	-3.8	-3.3	-1.4	-0.5
1987	-0.1	0.0	-0.4	-0.3	0.3	1.1	-3.5	2.0	-7.2	4.6	1.6	1.5
1988	0.0	-0.2	-0.4	0.0	-0.6	1.9	5.0	3.4	13.5	-2.6	-1.1	-1.0
1989	-0.5	-0.2	2.0	-0.2	-0.5	5.8	2.9	3.4	0.0	-2.6	-1.5	-0.9
1990	-0.4	-0.2	-0.4	-0.4	7.1	5.0	-8.6	10.2	-3.8	9.0	-0.4	-0.1
1991	-0.4	-0.2	-0.4	0.2	-0.3	6.4	-3.5	-7.6	-7.5	-3.1	-1.7	-1.3
1992	-0.6	-0.2	-0.4	-0.2	-0.5	4.6	-11.7	1.0	-1.7	-0.7	0.5	0.0
1993	-0.4	-0.2	-0.1	-0.3	-0.4	-2.8	4.3	-1.1	-2.7	4.1	-0.4	2.8
1994	0.6	-0.1	-0.4	0.5	-0.1	-1.4	-1.2	-0.2	-6.0	0.0	1.1	0.6
1995	2.4	0.0	0.9	0.3	0.1	0.0	1.3	-5.0	-1.8	5.0	-0.7	-0.4
1996	-0.4	-0.2	-0.4	0.2	-0.8	-4.5	2.6	3.3	3.2	3.1	-0.5	-0.3
1997	0.0	-0.2	0.1	0.4	-0.4	-3.5	-0.5	-2.8	-0.5	2.5	4.8	5.1
1998	2.9	0.1	-0.2	-0.3	-0.4	2.9	0.7	3.5	3.6	4.7	1.1	0.7
1999	-0.2	0.1	-0.4	-0.4	0.1	0.2	-2.2	-3.0	2.6	3.2	-0.7	-0.5
2000	-0.4	0.0	-0.4	-0.3	0.1	3.1	-5.0	3.1	-6.9	-2.0	-1.3	-1.3
2001	-0.3	-0.2	-0.4	0.2	-0.8	1.1	-7.7	5.8	-5.1	5.8	-0.7	-0.5
2002	-0.1	0.0	-0.4	0.0	-0.4	6.2	**-12.7**	2.3	-2.9	-1.0	-0.6	-0.7
2003	-0.4	-0.2	-0.3	-0.1	0.7	-0.9	6.3	0.4	-4.4	-2.8	-1.5	-1.4
2004	-0.5	-0.2	-0.1	-0.3	0.8	-2.3	3.5	-6.1	0.5	-0.6	0.7	0.1
2005	0.4	-0.2	0.2	-0.3	-0.8	-4.5	**15.5**	-3.3	2.3	1.7	-0.8	-0.7
2006	-0.5	-0.2	1.3	-0.3	0.6	0.3	-3.2	7.4	1.9	-1.2	-0.8	-1.1
2007	-0.6	-0.2	-0.4	-0.3	-0.3	2.9	-6.3	-2.0	3.8	-3.7	-1.8	-1.4
2008	-0.6	-0.2	0.4	-0.2	-0.8	-3.7	-1.8	0.1	5.3	-2.2	-1.5	-1.6
2009	-0.6	-0.3	-0.4	-0.3	-0.5	-3.9	0.5	-0.3	-1.0	-0.6	2.7	1.8
2010	0.2	0.1	-0.2	-0.3	-0.6	-0.7	10.5	6.2	-0.9	-0.9	1.1	0.1
2011	-0.4	0.0	-0.4	-0.2	-0.7	-3.1	4.8	2.9	-4.6	-2.4	-1.5	-1.5
2012	-0.6	-0.2	-0.4	-0.3	-0.7	-3.5	1.5	-4.3	-3.0	0.1	-0.7	-0.5
2013	-0.4	0.3	-0.2	0.1	-0.5	1.5	5.0	-2.5	-1.0	1.4	-0.4	0.4
2014	-0.2	0.5	4.0	0.3	-0.5	-5.6	-2.0	1.3	-5.1	-3.0	-0.7	-0.8
2015	0.1	-0.1	1.4	1.9	-0.2	-0.7	-6.5	-0.9	0.2	-2.6	-1.3	-1.3
2016	-0.6	-0.1	0.2	-0.2	-0.5	1.7	3.9	-5.3	**7.2**	1.9	-0.8	-0.6
2017	-0.5	-0.2	-0.1	-0.4	-0.7	2.6	-8.4	2.9	-1.5	2.1	-0.6	-0.3

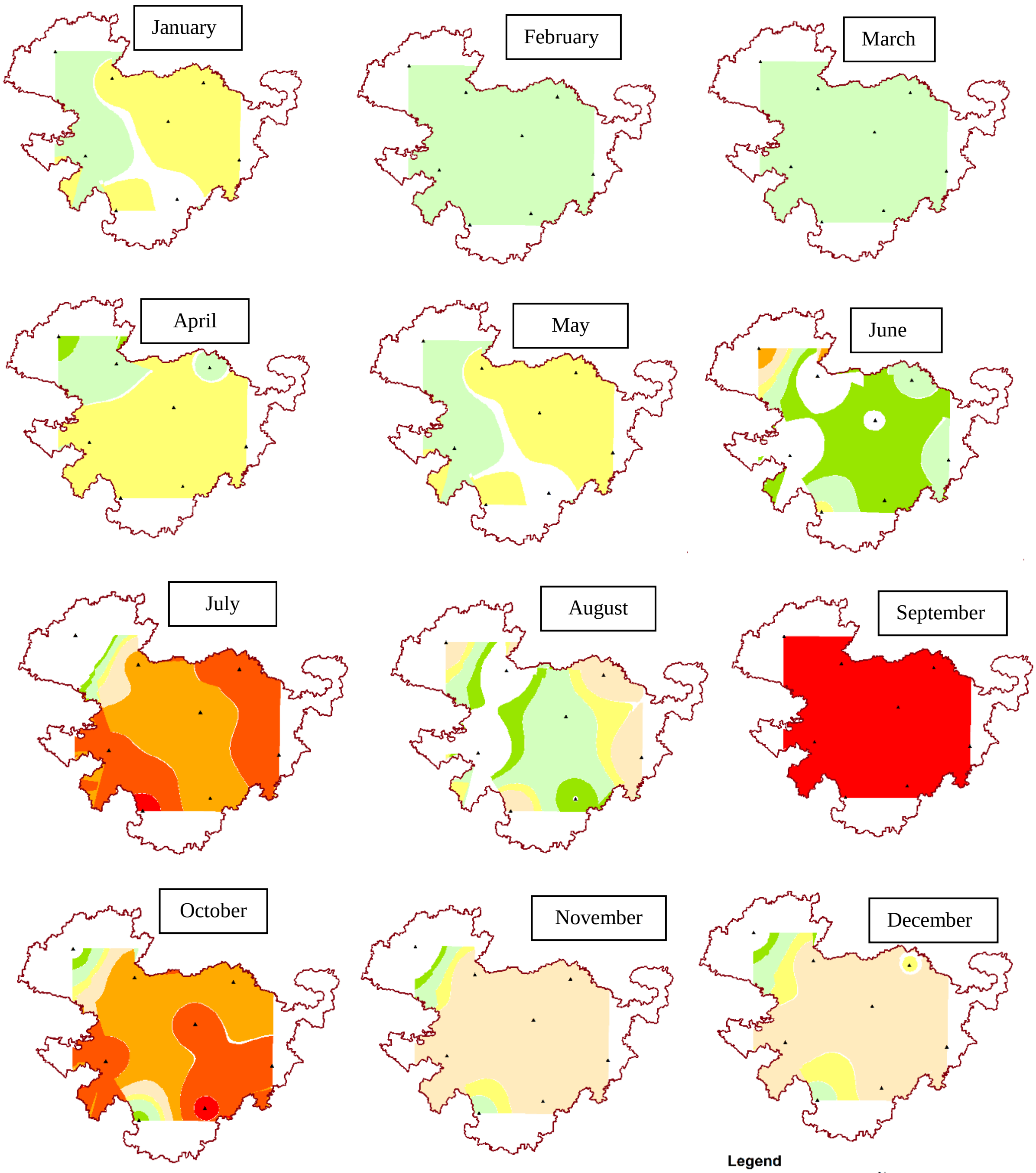
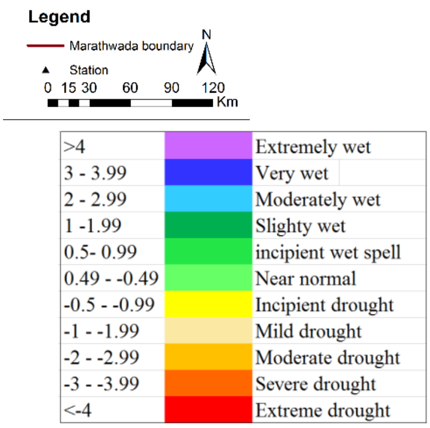


Figure 7: Spatial Representation of Marathwada Z-index for monthly average for period 1957 -2017



Lastly, the time-series of self-calibrated PDSI (scPDSI) is plotted in figure 8. The graph shows a severe drought period from 2004 to 2015, which is in line with the previous drought events observed for the region. As per the Z-index of PDSI, some years from 2004-2015 were not drought years, but ScPDSI shows the entire period as drought as constants are adjusted as per the local climatic conditions.

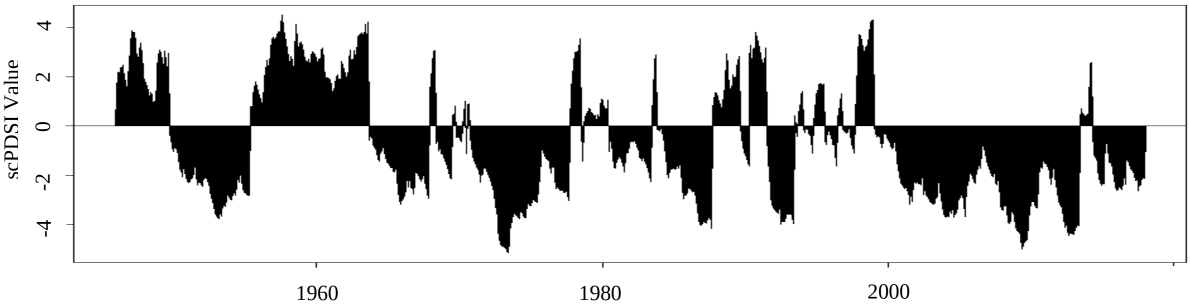


Figure 8: scPDSI plotted for 1957-2017

5. CONCLUSION

The Marathwada region is undergoing drought for past years, resulting in crop failure and water scarcity for other sectors. The approach used to analyze the water balance of the region defines the water surplus and water deficit of a region. The analysis shows the increasing trend of drought years shortly. The PDSI analysis shows the drought months for the period 1990-2017 have increased in number than the base year, i.e. 1957-1990. The soil moisture departure from April to September is high for 1957-1990, which is also affected due to the cropping pattern. The forest type seen in the Marathwada is thorn forest, where scrubs develop in dry areas with low rainfall. Hence, this study analyses the need for crop-shift to avoid crop damage during drought. Also, strategically changing the cropping pattern as per available soil moisture will reduce water resource scarcity in domestic and industrial sectors. Based on this analysis, preparedness and policy formation for the coming year can be considered since variation in Indian precipitation levels affects the agricultural sector.

The study thus helps in forming the strategies required to strengthen the policies to reduce the potential damages caused due to drought. Awareness programs and strict policies for better agricultural practices may be implemented for water balancing. All the urban system sectors need to augment short-term and long-term policies based on the analysis to overcome the water crisis for a balanced water resource.

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